ASSIGNING A VALUE TO DRIED DISTILLERS' GRAINS AS A PROTEIN SUPPLEMENT IN CATTLE CONSUMING LOW-QUALITY FORAGE

A Thesis

by

ZACHARY JOSEPH RAMBO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2010

Major Subject: Animal Science

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Approved by:

Chair of Committee,	Tryon Wickersham
Committee Members,	Chris Skaggs
	David Anderson
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ABSTRACT

Assigning a Value to Dried Distillers' Grains as a Protein Supplement in Cattle Consuming Low-Quality Forage.

(May 2010)

Zachary Joseph Rambo, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Tryon A. Wickersham

Cattle consuming low-quality forage may have decreased forage organic matter intake as a result of decreased nitrogen (N) intake. To date, a value has not been assigned to dried distillers' grains as a protein supplement to cattle consuming low-quality Bermudagrass forage. To address this shortcoming in the data, 13 duodenally and ruminally fistulated steers were arranged in an incomplete 13 × 4 Latin square with 13 treatments and 4 periods. Treatments were arranged as a 4 × 3 factorial plus a negative control (NC), which received no supplement. The first factor consisted of 4 levels of supplemental protein provided at 52, 104, 156, and 208 mg N/kg BW. The second factor consisted of one of three supplemental protein sources, cottonseed meal (CSM), dried distillers' grains (DDG), and dried distillers' grains plus urea (DDGU). Total digestible organic matter (TDOMI), and total organic matter intake (TOMI) increased in response to the increasing level of supplemental protein ($P < 0.01$). Similarly, digestible neutral detergent fiber intake (DNDFI) increased as a result of supplementation ($P = 0.06$). Forage organic matter intake did not increase as a result of protein supplementation ($P =$

0.20). However, forage organic matter intake (FOMI) responded quadratically to provision of CSM (P = 0.02). In contrast, DDG and DDGU did not significantly increase FOMI. Organic matter digestibility (OMD) tended to increase (P= 0.09) as a result of protein supplementation. Ruminal ammonia concentrations increased linearly in response to increasing provision of supplemental protein and were greater than control steers (P <0.01). Supplementation with DDGU resulted in the greatest increase in ruminal ammonia concentrations. Plasma urea nitrogen (PUN) concentrations increased in a linear fashion in response to CSM and DDGU supplementation (P <0.01), while provision of DDG resulted in a quadratic response (P = 0.08). Based on these results, DDG can be utilized as a protein supplement to increase TDOMI, however, it accomplishes this without significantly impacting FOMI which is in contrast to CSM.

DEDICATION

I would like to dedicate this thesis to my parents, Ira and Darlene Rambo.

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CHAPTER I

INTRODUCTION

Recent legislation supporting green and renewable energy sources in the United States has resulted in increased ethanol production from corn. A mandate derived from the Clean Air Act amendment of 1990, which revised fuel composition requirements in order to reduce carbon monoxide emissions, demands that 33 billion liters of ethanol be produced annually by 2012 (RFA, 2006a). Ethanol is the primary product of ethanol production; however, significant quantities of co-products are produced and can be utilized as feed in livestock rations. Corn gluten meal (CGM), corn gluten feed (CGF), crude corn oil, germ meal, and distillers' grains with solubles (DGS) are the primary co-products produced after fermentation and distillation (Rausch and Beylea, 2005).

Three primary methods are used to produce ethanol in the United States; wet milling, dry grinding, and dry milling. These methods vary in the amount of ethanol and type of co-products produced. Wet milling plants require the most capital investment and are typically owned corporately. The goal of wet milling is to isolate and recover the highly purified products of starch, including glucose, high fructose corn syrup, and ethanol. Of the three methods used in the US, dry grind mills produce the most ethanol per bushel of corn (Rausch and Belyea, 2005) and now account for 70% of total ethanol production (RFA, 2005).

This thesis follows the style of the Journal of Animal Science.

Wet milling differs from dry grinding and dry milling in that the corn is fractioned before fermentation. An individual corn kernel is fractioned into starch, germ, fiber, and protein through steeping. During steeping, corn is mixed with a weak solution of sulfuric acid. This process allows the solubles to leach from the germ while softening the corn kernel and improves the separation of kernel compounds. Steep water is classified as light steep water, 4 to 8% solids, or heavy steep water, 35 to 40% solids. Both light and heavy steep water contain 45 to 50% crude protein (CP). Germ and fiber fractions are removed according to density and particle size using hydrocyclones and screens, subsequently, the fiber fraction is mixed with heavy steep water to make corn gluten feed. Remaining solids, mainly starch and gluten protein, are then centrifuged to remove the protein fraction. The resulting slurry is hydrocycloned to remove the remaining protein, resulting in a highly purified starch concentrate that is greater than 99.5% starch, which is subsequently fermented to beer and distilled to remove the ethanol. Gluten protein is then centrifuged, dewatered by vacuum belt filtration, and flash dried to form corn gluten meal.

In comparison to wet mill plants, dry grind plants require less equipment and capital investment. Although they contribute less ethanol to the US's total production, they are of great benefit to rural economies and are often producer owned. To produce ethanol in a dry mill, the entire kernel is fermented and only DGS are produced as a co-product. Operations using dry grind attempt to maximize ethanol production per unit of energy. Basic steps in the dry grinding process include; grinding, cooking, liquefaction, simultaneous saccharification, fermentation, and distillation.

Grinding is accomplished through the use of hammermills or roller mills which reduce particle size and facilitate water penetration. Fines resulting from grinding are mixed with water to create a slurry which is cooked after liquefaction and the addition of amylase. Yeast and glucoamylase are added to aid in fermentation. Fermentation creates a beer, consisting of alcohol, water, and unfermented solids. Carbon dioxide is released when the beer is exposed to atmospheric pressure and subsequently distilled to separate the ethanol and water. Whole stillage from the bottom of the holding tank is centrifuged to yield wet grains and thin stillage. Moisture is evaporated from the thin stillage to result in condensed distillers' solubles which are added to wet grains to create DGS.

Fermentation of the corn kernel into ethanol alters the nutritional value of the co-product from that of corn. In short, all of the nutrients with the exception of starch increase in concentration. During the fermentation process approximately one third of corn is fermented into alcohol, another third is lost as CO_2, and the remaining third is left over as DGS. In essence, nutritive value of corn becomes concentrated into about one third of its original weight in the form of DGS (MacDonald, 2007). Nutritional data on DGS suggest that they are a high-quality feedstuff that can be effectively used in livestock diets (Table 1). Table 1 demonstrates that the fermentation of corn to ethanol and DGS through dry grinding alters the nutritional value of corn by increasing the concentrations of CP, ether extract, measures of fiber, and minerals. Conversion of corn into DGS decreases the undegradable intake protein (UIP) concentration, but DGS have a greater protein content than corn, thus DGS deliver more UIP than the same amount of corn. Differences in processing methods have been suggested to result in variation in

Table 1. Corn and DGS nutritive values (NRC 2000)

Item %	Corn	DGS
	% DM Basis	
Crude Protein	9.8	30.4
Undegradable intake protein, % of crude protein	55.0	52.0
Ether Extract	4.1	10.7
Crude Fiber	2.3	6.9
Neutral detergent fiber	10.8	46.0
Acid detergent fiber	3.3	21.3
Calcium	0.03	0.26
Phosphorus	0.32	0.83
Sulfur	0.11	0.44

nutritional value, between plants, and between batches of DGS from the same plant. Holt and Pritchard (2004), in an effort to quantify this variation, compared the nutritive values of DGS from four different plants in the upper Midwest (Table 2). Average nutritive value differed slightly from those listed in the NRC; however, in contrast to widely held beliefs, they were relatively consistent across plants.

Table 2. Comparison of DGS nutritive values from four different ethanol plants in the Midwest

Item %	Plant A	Plant B	Plant C	Plant D	SEM
Crude protein	33.1	34.0	36.7	30.6	0.51
Neutral detergent fiber	40.2	37.3	48.9	45.3	0.72
Acid detergent fiber	14.0	10.9	16.0	12.8	0.47
Ether Extract	13.5	13.3	10.3	14.2	0.40

Holt and Prichard (2004)

There are several reasons why DGS can vary in nutritional value. Distillers' grains with solubles are made by combining wet grains and syrup and the nutrient

composition of these two products can vary. Syrup can vary in protein content from 16 to 30 % (Rausch and Belyea, 2005). Additionally, the protein content of wet grains can vary. Further increasing the variability is a lack of precision in the blending of syrup and wet grains. All of these factors combine to result in nutritive values for DGS that are potentially divergent. Additional processing factors, such as type of fermentation (continuous vs. batch), drying temperature and duration, and percent of solubles added back to distillers' dried grains can influence the nutritional quality of DGS. Completeness or duration of fermentation also influences the amount of starch removed, further impacting consistency (Spiehs et al., 2002). Variation in corn composition and conditions in which it is grown can also contribute to differences in nutritional value. Nutrient content of soil can influence some nutrient concentrations in corn and ultimately DGS, especially minerals; however, most variation in DGS is due to differences in corn crop used and processing methods.

Phosphorous (P) and sulfur (S) content of livestock diets is a concern for producers and nutritionists. High P levels in a feedstuff increase dietary P levels and resulting P excretion, creating waste management and disposal challenges. Additionally, the need to balance for an appropriate calcium to P ratio requires the contribution from all feedstuffs to be accounted for. In addition to the challenges associated with P, high S levels may lead to excessive levels of sulfide in the rumen, causing a microbial shift towards bacteria that produce high levels of thiaminase. As a result, less thiamin is available for absorption through the rumen subsequently leading to a thiamin deficiency and ultimately polioencephalomalacia. Sulfur concentrations in DGS are most likely

increased by the use of sulfuric acid which is used to maintain fermenter pH levels (Crawford, 2007).

Dried distillers grains with solubles is a high-quality feed source available to livestock. High protein, energy, and fiber values make DGS especially utilizable for inclusion in cattle rations. Feedlot and dairy rations can often be formulated to include DGS without negative performance or health impacts on the animal (Anderson et al. 2006, Janicek et al. 2008, Powers et al. 1995, Leupp et al. 2009a, Leupp et al. 2009b, and Depenbusch et al. 2009). Removal of starch during the fermentation process and the increase in CP content increase the suitability of DGS as a supplement in grazing cattle. In fact, DGS may be ideally suited for cattle grazing low to medium-quality forage.

Forages vary in their nutritional quality depending on the species, stage of maturity, level of soil fertility, and myriad of environmental factors. Ideally, producers match forage-quality to cow requirements such that forage quality is lowest when cow requirements are the lowest. However, producers are often required to utilize low-quality forage for a significant period of the year and to maintain a satisfactory level of performance supplementation is often required. Forage quality is inversely related to the amount of dietary fiber it contains. As fiber content increases quality is typically reduced. As fermentation rates slow, diet digestibility is reduced, and CP content is insufficient for microbial fermentation. Low-quality forage is most often observed as plants mature, which results in decreased nutritive value because of higher levels of lignification, which leads to decreased digestibility, and a decreased leaf to stem ratio.

Production of microbial crude protein (MCP) is driven by the availability of energy and ruminally available N. Higher rates of fermentation and digesta passage result in greater MCP production, where as low-quality forage tends to reduce both fermentation and passage rate, limiting MCP production. Inadequate ruminally available N further compounds the problem of reduced fermentation because ruminal microbes don't have sufficient N to unlock the energy in forage. When forages are less than 6-8% CP, neither the diet or endogenous N cycling supply sufficient N to meet ruminal requirements translating to reduced intake, digestibility, or both.

Van Soest (1994) suggests that low-quality forages (forages<6-8% CP), have fermentation rates barely adequate to meet microbial maintenance requirements, thus setting limits on ruminal production of volatile fatty acids (VFA) and MCP. Köster et al. (1996) suggests degradable intake protein (DIP) is considered to be the dietary component that is "first limiting" to the utilization of low-quality forage. Low N content of low-quality forage can also limit the efficiency of MCP production by slowing both fermentation and passage rate, two major forces in MCP synthesis. Supplementing protein when forage CP is low can improve rumen function, which in turn allows for greater forage utilization allowing for improved animal performance in situations of diminished forage quality.

Undegraded intake protein, commonly referred to as escape or bypass protein, is protein that is protected from rumen fermentation. Undegraded intake protein can address the metabolizable protein (MP) requirements of the animal when MCP flow is inadequate. Examples of scenarios where this is of great importance include lactating dairy cows or

rapidly growing animals. When UIP is provided in excess of the animal's requirements for MP the carbon skeletons are metabolized for energy and have the potential to increase the glucose supplied to the animal. Ammonia, another product from amino acid catabolism, is detoxified to urea which can be subsequently recycled to the gastrointestinal tract or excreted in the urine. Wickersham et al. (2009) demonstrated the ability of ruminants fed low-quality forage to utilize recycled urea-N for the synthesis of MCP. By definition, DIP is subjected to degradation by rumen microbes. Degradation of DIP to amino acids and ammonia may seem inefficient; however, it is a required step for microbial growth and has the potential to improve protein quality. Adequate supplies of ruminally available N are required to maintain microbial populations and supply MCP, the primary source of MP in ruminants. Supplemental DIP can improve forage organic matter intake and digestion (FOMI and FOMD, respectively) of low quality forage, translating into improved animal performance. This is possible because DIP provides a source of ruminally available N (Wickersham et al. 2008b). Ruminally available N is used along with fermentable OM by rumen microbes to synthesize nitrogenous compounds, allowing microbes to grow. It also increases microbial activity, which improves animal energy status via increased VFA production while improving the protein status of the animal by increasing MCP flow to the duodenum (Scott and Hibberd, 1990; Köster et al., 1996; Wickersham et al. 2008a).

In most cases, the goal of protein supplementation is to ensure that cattle maintained on low-quality forage retain sufficient body weight (BW) and condition score (BCS) to successfully rebreed after calving. Therefore, the most useful measure of

response to protein supplementation are pregnancy status, BW, and BCS. However, due to the expense and difficulty of measuring these responses, researchers often measure intake and digestion to indicate the response to supplementation. For day to day management, producers monitor responses to supplementation through visual appraisal of BCS and BW change. Body weight is a contributing factor to BCS, with heavier cows often exhibiting greater body condition scores at a given frame size. Body condition score is related to conception rate in beef cows, with a BCS of 5 to 6 recommended at breeding for optimum conception rate (Fields and Sand, 1994). Forage quality can have a significant effect on BW and BCS in cows. Research by Halloway et al. (1979) showed that lactating cows grazing high-quality forage were heavier and had higher BCS than cows grazing low-quality forage. Stocker operators utilizing low-quality forage can also measure responses to supplementation through gains or losses in weight during the set grazing period.

Research by Kartcher (1981), compared the effects of supplementing cracked barley and cottonseed meal (CSM) to cows grazing dormant native forage. He reported that cows supplemented with CSM had numerically greater BW gain; however, no significant changes were noted for BCS in the first trial. In a second trial, cows were subjected to a more severe winter and cows supplemented with CSM lost less BW and BCS than barley supplemented and un-supplemented cows. While these results are not conclusive, evidence suggests protein supplementation improved performance on dormant forage. Similarly, Mathis et al. (1999) reported that BW and BCS losses were reduced by increasing levels of supplemental SBM, in cows grazing low-quality forage. However, a

plateau was observed in both BW and BCS losses, with the break-point in the plateau occurring when supplementation levels reached approximately 0.3% of BW. Below this point, BCS decreased 0.5 units for each 0.1% BW decrease in supplementation. Concomitantly, additional SBM above 0.3% BW did not improve BCS or BW. Even though changes were noted in weight and BCS, no differences in pregnancy rate, calf birth weight, or calf performance were noted in the study. In a companion project, Mathis et al. (1999) evaluated the impact of supplemental SBM on intake, digestion and ruminal fermentation. In this study, Mathis et al. (1999) demonstrated that delivery of supplement that is high in CP and DIP increases the utilization of low-quality forage through increased intake and digestion. Ultimately, this improvement in forage utilization translates into improved cow performance. Forage organic matter intake in their study followed a response curve similar to that of BW and BCS in that FOMI was not improved when supplemental SBM surpassed 0.16% of BW, the point of maximum FOMI. Digestible OMI and total tract OM and NDF digestibility continued to increase with increasing level of SBM supplementation, with the greatest increase occurring with the first increment of supplementation.

Larson et al. (2009) reported similar changes in BW and BCS when cows grazing corn crop residue or dormant range were supplemented with protein. They reported that protein supplemented cows had greater pre-calving and pre-breeding BW and BCS as compared to the un-supplemented group. However, these advantages in BCS and BW did not correlate to an increase in pregnancy rate, which is likely due to the fact that the average BCS of all treatment groups was greater than 5 prior to breeding. While

improved pregnancy rates were not observed, steer calves from protein supplemented dams had heavier body weights than steer calves from un-supplemented dams. As a result, calves from protein supplemented dams also had heavier hot carcass weights and greater marbling scores.

In accordance with the results from both Larson et al. (2009) and Mathis et al. (1999), research by Stalker et al. (2006) concluded protein supplementation of spring calving beef cows grazing dormant range during late gestation did not improve subsequent reproductive performance. Additionally, Stalker et al. (2006) reported protein supplemented cows grazing range and fed hay diets, with CP levels consistent with low-quality forage, lost less and even gained more pre-partum weight than unsupplemented cows. Concomitantly, pre-partum BCS loss was also reduced. Post-partum BCS changes were similar across all treatment groups. However, despite the changes in BW and BCS, no change for pregnancy rate, days of calving to pregnancy, or first 21 d conception rates were detected. Unsupplemented cows averaged BCS of 4.7 at calving in the study, which Stalker hypothesized to be the threshold at which increasing BCS no longer improves reproductive performance, partially explaining the lack of reproductive response in this project.

Smith et al. (2001) showed similar reproductive responses to supplementation with DGS. Even though a greater percentage of cows were cycling prior to estrus synchronization, artificial insemination conception rate and total conception rates were not different from cows supplemented with alfalfa, alfalfa plus cull beans, or DGS plus cull beans while grazing native winter range. Further results from this study showed that

when an isonitrogenous diet was fed, cows supplemented with DGS had the greatest numeric loss of BCS during the trial period. Cows supplemented with alfalfa or alfalfa plus cull beans lost less weight than the DGS supplemented group. From these results, Smith et al. (2001) concluded that DGS may be better suited when UIP demands are high.

Metabolizable protein (MP) requirements are important for production animals and need to be considered in low-quality forage situations. Metabolizable protein is the sum of digestible true protein contained in MCP and UIP where MP = (MCP × 0.8 × 0.8) + (UIP × 0.8). Microbial crude protein is considered by the NRC (2000) to be 80% true protein and 80% digestible, whereas UIP is considered to be 100% true protein and 80% digestible. Together, MCP and UIP must meet MP requirements. Microbial crude protein, or protein synthesized in the rumen by microbes, is an important contributor to the MP pool and can supply half of, or nearly all of the MP required by beef cows depending on forage UIP concentration (Anderson et al., 2001). However, in order for MCP production to be maximized, DIP requirements must be met. Without sufficient DIP, MP supply is limited because of reduced microbial growth in the rumen.

Lardy et al. (1998) concluded that cattle grazing low-quality forage can become deficient in both DIP and MP. Research regarding the effects of DIP and UIP on the performance of lactating first-calf heifers by Anderson et al. (2001) evaluated heifer performance when DIP and UIP levels were adequate and/or inadequate. Lactating heifers deficient in both DIP and UIP had the greatest weight loss during the 60-d treatment, compared to heifers supplied with adequate levels of DIP and MP, who had the highest weight gains. Heifers supplemented with adequate DIP but deficient in MP had

greater weight gains than both DIP deficient groups, their response was also similar to that of the group supplemented with adequate DIP and MP. Their increase in weight gain corresponded to a positive increase in BCS as well, where as the group deficient in both MP and DIP showed a loss of BCS.

Additional work by Sletmoen-Olson et al. (2000) found similar results when preparturient cows fed low-quality prairie hay (CP 5.8%) were supplemented with increasing levels of UIP. Their results showed that FOMI was similar across treatment groups during months 7-9 of gestation. Body weight of supplemented cows was greater than controls for 4 months of the study; however, level of UIP supplementation did not influence cow BW overall, indicating that UIP did not increase BW during the trial period. Body condition scores were not different among treatment groups during months 7 and 8 of gestation or months 1 and 2 of lactation. However, during month 9 of gestation and month 3 of lactation, BCS of controls was lower that that of supplemented cows. No treatment effects were noted for days to first estrus or rebreeding, which agrees with previous work. They concluded that additional UIP in the diet has little benefit when DIP is adequate.

Stocker cattle operations can also face low-quality forage situations, especially during the winter grazing months. As a result, supplementation is often needed to address protein deficiencies for satisfactory gains in stocker calves. Bodine and Purvis (2003) evaluated the impact of supplemental energy and/or DIP on beef steers grazing dormant tallgrass prairie. Steers supplemented with 0.96 g of SBM per kg of BW (dry matter basis) gained 0.39 kg per day as compared to un-supplemented control steers that lost

0.17 kg per day during the trial period. Average daily gains in this situation may have improved because of increases in FOMI, FOMD, and digestible organic matter intake (DOMI). These results show that supplementing protein to stocker calves grazing low-quality forage can improve weight gains and can be used as a tool to improve gains for producers.

Morris et al. (2005) compared the effects of supplementing increasing amounts of DGS to heifers grazing either low-or high-quality forage. Low-quality forage was defined as brome hay with 53% TDN and high-quality forage was defined as alfalfa hay and sorghum silage mix with 65% TDN. They reported that average daily gain increased linearly with DGS supplementation and that the greatest response was observed in heifers grazing low-quality brome hay.

Numerous studies have documented the impact of protein supplementation on intake and digestion in cattle grazing low-quality forage. Significant changes in FOMI, total organic matter intake (TOMI), neutral detergent fiber digestion (NDFD), and acid detergent fiber digestion (ADFD) have been documented in multiple projects and across numerous laboratories. Mathis et al. (1999) studied the effects increasing levels of SBM to beef steers fed low-quality forage. Steers were supplemented SBM at 0, 0.08, 0.16, 0.33, or 0.50 % of BW. Forage organic matter intake increased with level of supplementation and was maximized at 146% of control, this occurred when SBM was provided at 0.16% of BW. Provision of additional supplement beyond 0.16% of BW did not increase FOMI. Digestible organic matter intake increased linearly as expected with increases in supplement provision. Neutral detergent fiber intake also increased with

supplementation with the greatest intake observed at the highest level of supplementation. Neutral detergent fiber digestibility showed a cubic effect for level of supplementation. While NDF digestibility continued to increase with level of SBM supplementation, the greatest percent increase in digestibility was observed with the first increment supplementation.

The effects of corn condensed distillers solubles (CCDS) supplementation on steers fed low-quality hay by Gibery et al. (2006) showed similar responses. Steers fed low-quality forage were supplemented at 0, 5, 10, or 15 % of forage intake on a dry matter basis with CCDS. Hay DMI increased with supplementation at all levels with the highest increase in intake reported at the 5% supplementation level. Total intake increased linearly as expected with supplementation. Neutral detergent fiber intake also increased with supplementation with the highest levels observed at the 5% supplementation level and the highest ruminal NDF digestibility at the 10% supplementation level. Acid detergent fiber intake and ruminal digestibility was the highest at 5 and 10% level, respectively. It should be noted however that while there were numeric differences noted in this study, none of these values were statistically significant and overall, CCDS supplementation had no effect on total tract ADF and NDF digestibility.

Protein degradability has a significant impact of low-quality forage utilization. Supplements vary in DIP and UIP concentration. For example, blood meal is almost exclusively UIP, while other feedstuffs, such as CSM and DGS will have greater DIP values. Increased levels of DIP can improve forage utilization, while increases of UIP

can help offset a MP deficiency that may result from inadequate intake. Bohnert et al. (2002) reported the influence of protein degradability and supplementation frequency on steers consuming low-quality forage. They used CSM as a high DIP supplement and blood meal as a high UIP supplement. Steers supplemented with CSM had the highest FOMI, followed by bloodmeal and control groups, respectively. While there was a numeric difference in FOMI, these values were not statistically significant. There was a tendency for UIP and DIP to affect NDF intake. Steers supplemented with DIP had greater NDF intake than UIP and control groups. Atkinson et al. (2007) studied the impacts of increasing UIP to lambs fed low-quality forage. Control lambs were supplemented to meet estimated DIP requirements while treatment groups were fed increasing amounts UIP, which supplied 50, 100, or 150% of the CP provided by the control diet as UIP. Forage OM, NDF and ADF intake from was not different between control and UIP supplemented groups; likewise, increasing level of UIP was reported to have no significant effect on NDF or ADF digestibility. Results from this study suggest UIP has little effect on intake and digestion of forage.

Work by Köster et al. (1996) looked at the effects of increasing DIP on intake and digestion of beef cows grazing low-quality tallgrass-prairie forage. Animals were ruminally infused with 0, 180, 360, 540, or 720 g of DIP per day. The source of protein in this study was casein which is high in CP and is highly degradable, thus it provides a relatively pure source of DIP. Forage organic matter intake increased quadratically in response to increasing levels of DIP supplementation. Similar results have been subsequently reported by Kansas State University (Klevesahl et al. 2003, Wickersham et

al. 2008a, and Wickersham et al. 2008b) using a similar forage and casein as a supplemental source. A portion of this response can be accounted for by the increase in digestible OM provided by casein directly. True ruminal OM digestibility increased linearly in response to increasing levels of supplemental casein.

In addition to the impact of type of protein, UIP vs DIP in the supplement, the CP content of the forage exerts a significant impact on the response to supplemental protein. When three forages of differing CP content were supplemented with equivalent DIP, the response was different though all three were predicted to be deficient in DIP (Mathis et al., 2000). Intake of sorghum hay (4.3% CP) as well as digestion of OM and NDF were increased with the provision of supplemental DIP. In contrast, supplementation did not elicit improvements in forage utilization for either Bermudagrass or bromegrass hays, 8.2 and 5.9% CP, respectively. These results, at least for the Bermudagrass, support the conclusion of Moore and Kunkle (1995) that an increase in forage utilization in response to supplemental protein is less likely in forages with greater than 7% CP. However, prediction of DIP requirements would suggest a response to supplemental DIP for all three forages. These results suggest the prediction of DIP requirements may be inadequate, that our prediction of DIP supply may be inaccurate, or N is being supplied to ruminal microbes from sources other than dietary protein, for example, urea recycling. These findings may influence the impact of DGS as a protein supplement. Distillers' grains with solubles have less DIP than other protein supplements. As a result, supplemental DGS may not be effective in supplying rumen bacterial populations with sufficient N for growth and maintenance. Drying of DGS may also alter the composition

of protein by increasing the UIP content, (Klopfenstein, 1996, Van Soest, 1994) further reducing the ability of DGS to supply ruminally available N. The higher UIP concentration of DGS may prove beneficial to animals with high UIP demands. Lactation, gestation, and growth are all periods in which higher levels of UIP may be needed to meet the animal's total protein demands.

Ruminal ammonia is a key element for optimal forage utilization and is directly related to DIP supply. Ammonia is required by many carbohydrate fermenting microbes for growth and maintenance. Ammonia is required for MCP synthesis in which ammonia is recombined with carbon skeletons from structural carbohydrate fermentation (Van Soest, 1994). Growth is achieved when rumen microbes are able to synthesize nitrogenous compounds from ruminally available sources of N and fermentable organic matter. There are several sources of ruminal ammonia. Protozoa have been reported to be responsible for extensive ammonia production, some of which can be utilized by microbial populations (Warner, 1956). Russell and Wilson (1988) reported that rumen bacteria, especially *Clostridium* sp (strain R) and *Peptostreptococcus* sp (strain C) are capable of producing ammonia. Recycling of endogenous N, especially urea, is a significant ammonia source for rumen microbes though it remains largely unquantified. Urea, present in the saliva and blood, can diffuse across the rumen wall where it is converted to ammonia. In low N situations, a large portion of N metabolized in the animal is recycled, largely through the rumen (Wickersham et al. 2008b, and Wickersham et al. 2009). Recycling of urea from endogenous metabolism of tissue and amino acids can also contribute to the ruminal ammonia pool.

In low-quality forage situations, ruminal ammonia concentrations are improved with supplemental protein. Köster et al. (1996) reported increasing levels of DIP from casein supplemented to cattle consuming low-quality (1.94% CP) forage, increased ruminal ammonia concentrations increases linearly with the highest levels of ammonia concentrations reported at the highest level of DIP supplementation. Wickersham et al. (2008a, 2008b) reported that ruminal ammonia concentrations increased linearly with increasing DIP supplementation from casein. Similar results were reported in earlier work by Mathis et al. (1999) when increasing amounts of SBM were supplemented to steers consuming low-quality forage. Beef steers supplemented with CSM had greater rumen ammonia levels than un-supplemented steers while consuming 6% CP grass hay (McCollum and Galyean, 1985). Daily supplementation of DGS at 0.4% of BW to heifers fed chopped grass hay (8.2% CP) by Loy et al. (2007) also concurs with previous reports that ruminal ammonia concentrations improve in response to protein supplementation. Reed et al. (2007) reported that ruminal ammonia concentrations increased in response to increasing level of UIP supplementation when low-quality (6.0% CP) forage was fed.

Changes in VFA production and ratios are also expected in response to protein supplementation. Total VFA production increases in response to improvements in FOMI, fermentation of supplemental protein would also contribute carbon skeletons to the VFA pool. Köster et al. (1996) reported that total VFA production increased linearly in response to increasing level of casein supplementation when steers were fed low-quality (1.94% CP) prairie hay. Concentrations of acetate declined linearly while propionate

concentrations increased linearly with increasing level of supplementation, subsequently, a linear decline in the acetate to propionate was reported. Butyrate concentrations were not affected; however, isobutyrate, valerate and isovalerate concentrations all increased linearly. Later results reported by Wickersham et al. (2008a, 2008b) also noted that that total VFA concentrations increased, acetate concentrations decreased and propionate concentrations increased in a linear fashion in response to supplemental casein in steers fed 4.9% CP hay. Mathis et al. (2000) reported conflicting results to supplemental casein on forages of three different qualities. Total VFA concentrations increased in response to supplemental casein when sorghum hay (4.3% CP) were fed, however, VFA concentrations were not increased when bromegrass and Bermudagrass hays were fed (5.9% and 8.2% CP). McCollum and Galyean (1985) also reported that supplemental CSM improved VFA concentrations in steers fed low-quality (6.1% CP) prairie hay. Steers supplemented with CSM also had higher acetate concentrations than controls. These results indicate that forage quality contributes to VFA production and supplemental protein may not elicit an effect on VFA production when forage CP is greater than 5.9%.

Mathis et al. (1999) also reported that total VFA production increased linearly when SBM was supplemented to steers consuming 5.3% CP hay. Concentrations of both acetate and propionate however responded cubically, resulting in a cubic increase in the acetate to propionate ratio, which declined at higher levels of SBM supplementation. When CCDS were fed to steers consuming 5.1% CP hay total VFA was not affected; however, acetate concentrations were reported to decline linearly and propionate concentrations were unaffected (Gilbery et al. 2006). In contrast, Loy et al. (2007)

reported increased total VFA concentrations when DGS were supplemented daily to heifers consuming 8.2% CP hay. Concentrations of acetate and propionate were not different amongst DGS treated groups and un-supplemented controls; subsequently the acetate to propionate ratio was not affected.

Plasma urea nitrogen **(**PUN) is typically affected by protein supplementation and can be used as an indicator of animal protein status. Endogenous urea is an important source of N for ruminants because of urea recycling. As level of DIP supplementation increases it results in increased PUN (Wickersham et al. 2008a). Similar results were noted by Loy et al. (2007) in which PUN concentrations increased in response to protein supplementation. Bohnert et al. (2002) also reported that cows supplemented daily with DIP or UIP had higher PUN concentrations than non-supplemented controls. Reed et al. (2007) reported steers fed increasing levels of DIP had higher blood urea concentrations than non-supplemented controls.

Low-quality forage often contains inadequate amounts ruminal degradable N resulting in low ruminal ammonia concentrations contributing to limited MCP synthesis and growth. Ultimately, this limits microbial fermentation of fiber, digesta outflow, and forage intake (Gilbery et al., 2006). As previously discussed, protein supplementation can improve intake and digestion of low-quality forage. The ratio of DIP to UIP and the CP concentration of a supplement are two important factors to consider when matching a supplement. According to the NRC (2000), the average protein content of DGS is 30.4%, of which 52% is DIP, leaving 48% of the CP content available for rumen degradation, which is lower than CSM and SBM, 57 and 66% DIP respectively. However, in relation

to these same feedstuffs, it is higher in EE, suggesting DGS will supply more energy than other commonly uses protein supplements. Heat treatment can also alter the nutritional composition of DGS, making protein more inaccessible to digestion. These factors create pros and cons for utilizing DGS as a protein supplement. Increased UIP and EE would be beneficial when energy and UIP were limiting in the diet, such as lactation. The lower percent DIP of DGS may limit its effectiveness as a supplement if improving forage utilization is the primary goal. Lower DIP content in conjunction with possible heat damage may reduce the available N to rumen bacteria for growth and maintenance. As a result, it may be necessary to include rapidly fermentable forms of N, such as urea, to DGS supplements in order to improve their ability to contribute to the animal's N pool.

CHAPTER II

MATERIALS AND METHODS

Design

Thirteen duodenally and ruminally fistulated steers (average initial BW 463 kg ± 42 kg) were used in a 13 × 4 incomplete Latin square with 13 treatments and 4 periods (Cochran and Cox, 1952). Treatments were arranged as a 4 × 3 factorial plus a negative control (NC), which received no supplement. The first factor consisted of 4 levels of supplemented protein provided at 52, 104, 156, and 208 mg N/Kg BW. The second factor consisted of one of three supplemental protein sources, cottonseed meal (CSM, Table 1), dried distillers grains (DDG), and dried distillers grains plus urea (DDGU). Levels of supplemental N provision were established from previous work using similar forage (Kunkel, unpublished data).

The experimental protocol was approved by the Institutional Animal Care and Use Committee at Texas A&M University and included the use of anesthesia when surgical procedures were performed. Steers were housed in an enclosed, climate controlled barn in individual pens (2.1 m x 1.5 m) with continuous lighting and ad libitum access to water and a trace mineral block (United Salt Corporation, Houston, TX). Low-quality bermudagrass hay, Table 3, was chopped through a wire screen and fed at 130% of the previous 4-d average intake to insure that access to forage was not restricting intake. The four experimental periods were divided into three phases: (1) 10 days adaptation to treatment; (2) 6 days of measurement of hay intake and digestion; (3) 1 day ruminal

sampling. Supplements were offered at 0630 each morning in an individual pan and hay was fed at approximately 0700. Approximately 1 kg of hay was retained daily for later analysis. During days 11 to 17 of each period, both voluntary hay intake and fecal output were determined. Hay and orts samples were collected on days 11 to 16, and total fecal output collected on days 12 to 17, were used to determine total tract digestion according to the guidelines of Cochran and Galyean (1994). Orts were removed at 0600 h and approximately 600 g per day were retained for analysis.

Table 3. Diet and supplement composition

Item	Hay	DDG[a]	CSM[a]	Urea
	% of DM			
CP	7.4	31.0	49.6	300.5
OM	92.9	94.7	90.8	100.0
NDF	77.0	44.6	27.3	-
ADF	41.2	11.5	18.6	-

[a]CSM = cotton seed meal, DDG = dried distillers' grains

On the day following the completion of fecal collections, ruminal fluid samples were collected by suction strainer (Raun and Burroughs 1962; 19 mm diameter 1.5 mm mesh) just before offering of supplement and at 1, 2, 3, 4, 8, 12, 16 and 20 h after supplementing. Immediately after sampling, ruminal pH was measured using a portable pH meter with a combination electrode. Eight ml of rumen fluid was combined with 2 ml of 1 N HCl and frozen for NH_3 analysis. Blood was collected from the jugular vein 12 h after supplementation for subsequent determination of plasma urea nitrogen and glucose concentration.

Laboratory Analysis

Partial DM of hay, orts, and fecal samples were performed by drying at 60˚ C in a forced-air oven for 96 h. All dried samples were then ground (No. 4 Wiley Mill, Thomas Scientific, Swedesboro NJ) to pass through a 1 mm screen. Hay samples collected during the measurement period were pooled across days and period. Ort and fecal samples were composited with animal and period. Hay, supplement, ort and fecal samples were dried for 24 h at 105˚ C in a forced air oven to determine DM and then combusted for 8 h at 450˚ C in a muffle furnace to determine OM. Nitrogen content of samples was determined by total combustion. Crude protein was calculated by N x 6.25. Samples were analyzed for NDF and ADF using the ANKON-Fiber Analyzer (ANKOM-Technology, Fairport, NY). Colorimetric determination of ruminal ammonia (Broderick and Kang, 1980), plasma urea (Marsh et al. (1965) and Broderick and Kang, 1980) and glucose (Glucose procedure #16-UV) were made using and UV/VIS (Sigma Diagnostics, St. Louis MO).

Calculations

Total tract digestion coefficients for DM, OM, and NDF were calculated, using the procedures described by Cochran and Galyean (1994).

Statistical Analysis

Intake and digestion were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary NC). Terms in the model included treatment and period with steer included as a random effect. Preplanned contrasts were used to separate the means. Contrasts were: 1) control vs. treatment, 2) linear effect of protein level, 3) quadratic effect of protein level, 4) CSM vs DDG, 5) DDG vs DDGU, 6) CSM vs DDGU, 7) CSM

linear, 8) CSM quadratic, 9) DDG linear, 10) DDG quadratic, 11) DDGU linear, 12) DDGU quadratic. Treatment means were calculated using the LSMEANS option and the same contrasts noted above were used to partition sum of squares.

CHAPTER III

RESULTS

Total organic matter intake (TOMI) was greater for supplemented steers than control steers (P <0.01; Table 4). Similarly, total digestible organic matter intake (TDOMI) and digestible neutral detergent fiber intake (DNDFI) was greater for supplemented steers than control (P <0.01 and P = 0.06, respectively). In contrast to these results, forage OM intake (FOMI) was not significantly different (P = 0.20) between control and supplemented steers. In accordance, increasing levels of protein supplementation resulted in linear increases in TOMI, TDOMI, and DNDFI (P <0.01), but there was no corresponding increase in FOMI (P = 0.28). No significant differences in any measure of intake were observed between DDG and DDGU (P = 0.12). Forage OM intake was greater for CSM than both DDG and DDGU (P <0.01 and P = 0.08, respectively). Steers supplemented with CSM had greater TOMI than those supplemented with DDG (P = 0.06) and tended to be greater than DDGU (P = 0.10). However, there was no difference in TDOMI between any of the sources of supplement.

Table 4. Effect of level of protein supplement and source on intake by beef steers consuming low-quality Bermudagrass hay

Protein level[a]	Protein source[b]	Intake, g/kg $BW^{0.75}$ Forage OM	Total OM	Total Digestible OM	DNDF[c]
0	-	39.5	39.5	21.0	17.7
52	CSM	43.4	44.6	23.3	18.5
104	CSM	45.3	47.7	26.5	21.2
156	CSM	45.9	49.5	27.7	21.4
208	CSM	41.9	46.7	27.7	20.3
52	DDG	41.4	43.4	24.1	19.8
104	DDG	37.7	41.5	23.7	18.8
156	DDG	41.3	47.1	28.1	21.8
208	DDG	39.0	46.9	27.3	20.3
52	DDGU	40.2	41.5	20.2	16.5
104	DDGU	42.5	45.1	26.0	21.5
156	DDGU	42.0	45.8	24.2	19.2
208	DDGU	42.7	47.7	28.4	21.8
SEM		2.35	2.34	1.61	1.34
				Contrasts	
Control vs Treatments		0.20	<0.01	<0.01	0.06
Protein main effects					
Linear		0.28	<0.01	<0.01	<0.01
Quadratic		0.16	0.16	0.53	0.33
Source					
CSM vs DDG		<0.01	0.06	0.59	0.80
DDG vs DDGU		0.12	0.82	0.27	0.62
CSM vs DDGU		0.08	0.10	0.11	0.46
CSM					
Linear		0.20	<0.01	<0.01	0.04
Quadratic		0.02	0.02	0.21	0.16
DDG					
Linear		0.84	<0.01	<0.01	0.06
Quadratic		0.88	0.91	0.58	0.48
DDGU					
Linear		0.16	<0.01	<0.01	<0.01
Quadratic		0.68	0.68	0.65	0.98

[a]Protein level, mg N/kg BW

[b]Protein source, CSM = cottonseed meal, DDG = dried distillers' grains, and DDGU = dried distillers' grains plus urea.

[c]DNDF = digestible neutral detergent fiber intake

Provision of increasing levels of CSM resulted in a quadratic increase in FOMI (P = 0.02), this is in contrast to both DDG and DDGU which did not significantly increase FOMI. Increasing levels of CSM resulted in a quadratic increase in TOMI (P = 0.02). Whilst increasing levels of DDG and DDGU resulted in linear increases (P <0.01) in TOMI. Total digestible OM intake and DNDFI were linearly increased (P = 0.06) with increasing levels of protein for all three sources of supplement.

Percent organic matter digestibility (OMD) tended (P = 0.09, Table 5) to be greater for supplemented steers than control steers; however, no corresponding increase in neutral detergent fiber digestibility (NDFD) was observed (P = 0.72). A linear increase in percent OMD was observed with increasing supplementation for all sources (P <0.01). Neutral detergent fiber digestibility increased linearly (P = 0.06) in response to increasing level of DDGU supplementation. In contrast, supplementation with increasing levels of CSM and DDG did not exert a significant effect on NDFD.

Table 5. Effect of level of protein supplement and source on digestibility by beef steers consuming low-quality Bermudagrass hay

		Digestibility, %	
Protein level[a]	Protein source[b]	OM	NDF
0	0	53.19	52.92
52	CSM	52.27	51.52
104	CSM	56.03	55.60
156	CSM	56.16	54.80
208	CSM	59.57	57.08
52	DDG	56.03	56.88
104	DDG	57.12	57.07
156	DDG	58.86	58.18
208	DDG	57.83	55.70
52	DDGU	48.99	48.87
104	DDGU	58.34	60.67
156	DDGU	52.80	52.39
208	DDGU	59.18	58.69
SEM		1.95	2.17
		Contrasts	
Control vs Treatments		0.10	0.72
Protein main effects			
Linear		<0.01	0.12
Quadratic		0.75	0.83
Source			
CSM vs DDG		0.22	0.10
DDG vs DDGU		0.03	0.17
CSM vs DDGU		0.32	0.76
CSM			
Linear		<0.01	0.20
Quadratic		0.42	0.35
DDG			
Linear		0.03	0.62
Quadratic		0.26	0.25
DDGU			
Linear		<0.01	0.06
Quadratic		0.32	0.50

[a]Protein level, mg N/kg BW

[b]Protein source, CSM = cottonseed meal, DDG = dried distillers' grains, and DDGU = dried distillers' grains plus urea.

Table 6. Effect of level of protein supplement and source on ruminal ammonia and ruminal pH in beef steers consuming Bermudagrass hay

Protein level[a]	Protein source[b]	NH_3 m*M*	pH
0	0	1.96	6.61
52	CSM	2.86	6.62
104	CSM	3.35	6.65
156	CSM	4.50	6.60
208	CSM	4.84	6.59
52	DDG	2.60	6.60
104	DDG	2.79	6.65
156	DDG	2.68	6.55
208	DDG	3.29	6.65
52	DDGU	3.92	6.55
104	DDGU	5.38	6.61
156	DDGU	6.66	6.59
208	DDGU	8.61	6.59
SEM		0.45	0.07
			Contrasts
Control vs Treatments		<0.01	0.90
Protein main effects			
Linear		<0.01	0.94
Quadratic		0.78	0.96
Treatment		<0.01	0.99
Hour		<0.01	<0.01
T x H		<0.01	0.36
Source			
CSM vs DDG		<0.01	0.93
DDG vs DDGU		<0.01	0.55
CSM vs DDGU		<0.01	0.49
CSM			
Linear		<0.01	0.78
Quadratic		0.78	0.64
DDG			
Linear		0.05	0.91
Quadratic		0.83	0.74
DDGU			
Linear		<0.01	0.99
Quadratic		0.90	0.81

[a]Protein level, mg N/kg BW

[b]Protein source, CSM = cottonseed meal, DDG = dried distillers' grains, and DDGU = dried distillers' grains plus urea.

Ruminal ammonia concentrations were greater for supplemented steers than control ($P < 0.01$; Table 6). As level of protein provision increased from 0 to 208 mg of N/kg BW, ruminal ammonia concentration increased linearly ($P < 0.01$). All sources of supplemental protein were different from one another ($P < 0.01$) with DDGU producing the highest ammonia concentrations followed by CSM and then DDG. Provision of DDGU, CSM and DDG resulted in linear increases in ruminal ammonia concentration ($P < 0.05$). Rumen pH was not significantly affected by any treatment ($P \geq 0.36$). However, hour of sampling was significant ($P < 0.01$) and largely related to depressions in ruminal pH after feeding followed by a subsequent return to nadir prior to the next feeding event.

Plasma glucose (PG) concentrations were greater ($P <0.01$; Table 7) for supplemented steers than controls. Linear increases were observed with each supplement source ($P <0.01$); however, the biological significance of these results is questionable. Plasma urea N (PUN) concentrations were greater in supplemented steers than in control steers ($P <0.01$; Table 7). Increasing provision of protein resulted in a linear increase in PUN ($P <0.01$). This linear relationship was consistent as level of protein provision increased for both CSM and DDGU. In contrast, DDG resulted in a smaller increase in PUN and the relationship between level of DDG and provision of PUN was quadratic ($P =0.08$). Additionally, the provision of CSM and DDGU resulted in greater PUN than DDG ($P <0.01$).

Table 7. Effect of level of protein supplement and source on plasma glucose and urea concentration in beef steers consuming low-quality Bermudagrass hay

Protein level[a]	Protein source[b]	Glucose, m*M*	Urea, m*M*
0	0	0.34	3.08
52	CSM	0.36	3.92
104	CSM	0.34	4.66
156	CSM	0.36	5.05
208	CSM	0.36	6.32
52	DDG	0.35	3.86
104	DDG	0.36	4.16
156	DDG	0.36	4.21
208	DDG	0.37	3.85
52	DDGU	0.35	3.59
104	DDGU	0.35	5.29
156	DDGU	0.37	6.35
208	DDGU	0.36	6.53
SEM		<0.010	0.38
		Contrasts	
Control vs Treatments		<0.01	<0.01
Protein main effects			
Linear		<0.01	<0.01
Quadratic		0.20	0.29
Source			
CSM vs DDG		0.65	<0.01
DDG vs DDGU		0.81	<0.01
CSM vs DDGU		0.49	0.10
CSM			
Linear		<0.01	<0.01
Quadratic		0.99	0.72
DDG			
Linear		<0.01	0.13
Quadratic		0.31	0.08
DDGU			
Linear		<0.01	<0.01
Quadratic		0.08	0.37

[a]Protein level, mg N/kg BW

[b]Protein source, CSM = cottonseed meal, DDG = dried distillers' grains, and DDGU = dried distillers' grains plus urea.

CHAPTER IV

DISCUSSION

This study was designed to determine the ability of DDG to modulate forage intake and digestion relative to a conventional protein supplement, in this case CSM. An additional objective was to determine if adding urea to DDG would improve its suitability as a supplement for addressing ruminal N deficiencies in cattle consuming low-quality forage. As expected, and in accordance with previous work (Köster et al. 1996; Mathis et al. 1999; Wickersham et al. 2008a) TDOMI increased with increasing provision of all three sources of supplement. While there was no significant differences between sources in TDOMI, each of the three supplements utilized (CSM, DDG, and DDGU) produced their respective increases differently.

Increasing provision of CSM resulted in a quadratic increase in FOMI. Similar quadratic responses to increasing provision of supplemental protein were described by Köster et al. (1996), Mathis et al. (1999) and Klevesahl et al. (2003). In further accordance with the aforementioned results, the greatest FOMI response was observed with the first increment of CSM provision, likely the result of increasing the supply of ruminally available N. Further additions of supplemental CSM produced smaller increases in FOMI, ultimately, reaching a plateau when CSM was provided at 156 mg N/kg. The forage utilization response observed to CSM indicates that though our Bermudagrass (7.4% CP) was similar to the 8.2% CP Bermudagrass used by Mathis et al. (2000), where supplemental DIP did not improve forage utilization, the potential for

forage utilization to respond to the delivery of supplemental protein was present with this forage.

In contrast to provision of CSM, delivery of increasing levels of DDG did not promote greater FOMI and when averaged across level of N FOMI was very similar to forage intake in control steers (39.8 and 39.5 g/kg $BW^{0.75}$, respectively). In a similar study, Loy et al. (2007) reported that FOMI was not increased with the provision of DDG in heifers fed forage containing 8.2% CP. Cottonseed meal and DDG differ in the CP content (49.6 versus 31.0% CP, respectively) and in the degradability of that protein, with the protein of DDG being less degradable than CSM, 26 versus 57% (NRC, 2000). Ruminal requirements for DIP are base on a ratio of total digestible nutrients to DIP (7:7:1; NRC, 2000). Delivery of a supplement increases the supply of total digestible nutrients to the rumen and must have a total digestible nutrients to DIP ratio of less than 7:7:1 to address a ruminal N deficiency. The CP content, the low degradability, and the high total digestible nutrient content of DDG result in a ratio (10:7:1) that is greater than both the requirement and CSM (2:7:1) indicating that DDG is not capable of directly addressing a protein deficiency. However, the high UIP content of DDG favors the catabolism of amino acids and the subsequent recycling of urea-N to the gastrointestinal tract. Nitrogen originating from UIP can then be used to address ruminal N requirements and stimulate forage utilization. Previous research has demonstrated that the forage utilization response to the provision of UIP is less (approximately 65% as effective as stimulating forage utilization) than the same amount of protein provided by DIP (Bandyk et al. 2001; Wickersham et al. 2004). Despite the reduced effectiveness of UIP both

authors reported significant increase in both FOMI and TDOMI when UIP was provided. Furthermore, Wickersham et al. (2009) demonstrated that increased level of UIP quadratically increased FOMI and TDOMI, while increasing both the amount and the proportion of MCP originating from recycled urea-N. In all three of the aforementioned projects forage CP was less than 5.3 %, which is in contrast to the 7.4% CP Bermudagrass used in this project. The low CP content of the forages used in their work resulted in PUN and ruminal ammonia concentrations of less than 1 m*M*. In contrast, PUN and ruminal ammonia of control steers in our project were 3.08 and 1.96 m*M*, respectively. Kennedy and Milligan (1980) concluded that low ruminal ammonia concentrations and increased PUN concentrations favor the transfer of PUN to the gastrointestinal tract, thus the higher ruminal ammonia concentrations observed in our study likely reduced the ability of urea-N from UIP in the DDG to meet ruminal N demands. Additionally, provision of supplemental UIP more than doubled PUN in both Bandyk et al. (2001) and Wickersham et al. (2004), favoring the transfer of PUN to the rumen. In contrast, PUN concentrations were 30% higher with the provision of DDG in our study. Vercoe (1969) reported that increases in PUN concentration above 4.3 m*M* lead to no further increase in urea entry into the rumen, suggestion only limited response surface for DDG to promote the transfer of urea-N in our study. Forage quality and elevated ruminal ammonia and PUN concentrations may have prevented DDG from indirectly stimulating FOMI through N-recycling mechanisms, in our study. However, DDG may have the potential to stimulate the utilization of lower quality forages by indirectly supplying ruminal N.

In contrast to FOMI, TDOMI increased with the provision of DDG such that there was no difference in TDOMI between CSM and DDG. In part, this is explained by the design of the project as sources of protein were delivered at levels designed to be isonitrogenous, hence when DDG was provided it was fed at approximately 160% the amount of CSM. Therefore, the contribution of supplement to increasing TDOMI was sufficient in steers supplemented with DDG such that the increase in TDOMI at each level of N provision matched the increase in forage utilization and supplement intake observed with CSM.

As previously stated, a challenge with using DDG to supplement cattle consuming low-quality forage is the relatively low DIP content of DDG. To overcome this, DDG can be blended with a source of highly degradable protein to improve the ability of DDG to address ruminal N deficiencies. Urea is a commonly utilized source of DIP because of its high CP content and high degradability. However, urea is rapidly hydrolyzed to ammonia and subsequently absorbed from the rumen. Van Soest (1994) suggested that rapid hydrolysis and subsequent absorption may limit the effectiveness of urea for promoting forage utilization. The DDGU supplement was formulated to contain the same amount of CP as CSM, which resulted in a mixture of 93.4% distillers' grains and 6.6% urea. This blend resulted in 39% of CP coming from urea, 71% of DIP coming from urea, and a total digestible nutrients to DIP ratio 3:3:1. Provision of DDGU, as expected, resulted in the highest ammonia concentrations at all levels of protein supplementation. Indicating that the inclusion of urea with DDG was effective at increasing the supply of ruminally available N. However, this did not result in a significantly greater FOMI than

DDG and was unable to match the observed increases in FOMI when CSM was supplemented. In contrast, Köster et al. (1997) reported only minimal differences in forage utilization when < 75% of the supplemental DIP was provided as urea. Their results and the results of Köster et al. (2002) would suggest DDGU should be as effective as CSM in promoting the intake of forage. It is likely that reduced N capture by ruminal microbes lead to a reduction in the ability of DDGU to promote FOMI and subsequent digestion of the basal forage. Additionally, the level of supplement consumption was less for DDGU than DDG; therefore, the increase in TDOMI associated with the provision of DDG did not occur with DDGU. In short, DDGU was only slightly more effective at stimulating FOMI than DDG, but because DDGU was provided in lesser amounts it was not able to match to consistent increases in TDOMI observed with CSM and DDG.

CHAPTER V

CONCLUSION

Supplementing protein to cattle consuming low quality forage is useful for increasing forage utilization and digestion during periods of the year where forage quality constrains animal performance. Increasing the utilization of existing forage resources provides producers with the opportunity to decrease cost and increase profitability. Our study demonstrates that the provision of dried distillers' grains and cottonseed meal can effectively increase the intake of nutrients by cattle consuming low-quality Bermudagrass. Cattle supplemented with dried distillers' grains maintained a similar level of forage intake as the unsupplemented controls but increased total digestible organic matter intake because of the contribution of the supplement and increases in digestibility. In scenarios where forage is purchased or limited, dried distillers' grains may provide an effective supplement for increasing total digestible organic matter intake without impacting forage utilization.

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